ECE 174

Intro to Linear & Nonlinear Optimization

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ECE Department UCSD

Contact Information – Fall 2017

- ▶ Course Website
  - Accessible from http://dsp.ucsd.edu/~kreutz/; Piazza: https://piazza.com/
- ▶ Course Lecture Time & Location
  - TuTh – 2-3:20pm, Center Hall, Room 109
- ▶ Instructor
  - Prof. Ken Kreutz-Delgado, kreutz@ece.ucsd.edu
  - Office Hour: Wednesday, Noon-1pm, EBU-I 5605
- ▶ Teaching Assistants
  - Ching-fu Chen, chc187@ucsd.edu
  - Luca Pion-Tonachini, lpionton@ucsd.edu
  - Ian Colbert, icolbert@ucsd.edu
- ▶ TA & Discussion
  - TA Office Hours: Monday, 2-3pm. Room Jacobs (EBU-1) 2315
    Discussion Section: Wednesday, 9:30-10:30am. Room Jacobs 2315
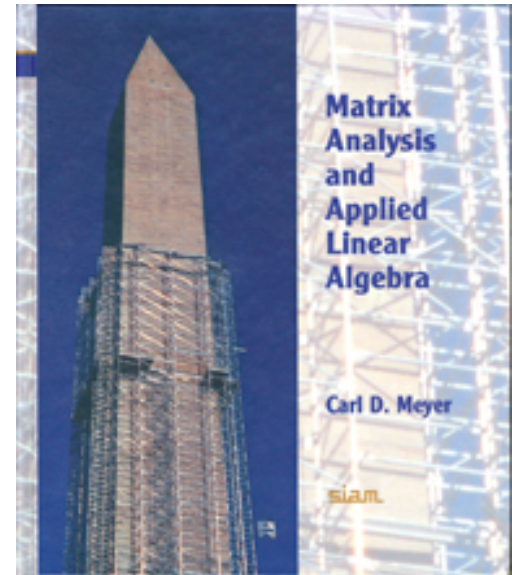- ▶ Administrative Assistant
  - Travis Spackman, tspackman@ece.ucsd.edu; (858) 822-4697, EBU-1 2908

Textbook

▶ *Matrix Analysis & Applied Linear Algebra*
Carl D. Meyer, SIAM, 2000
3rd printing is latest

▶ Suggested Supplemental Texts

- *Linear Algebra, 4th Edition*
S. Lipschutz & M Lipson
Schaum's Outlines, McGraw-Hill, 2009

- *Linear Algebra and its Applications, 4th Edition*
G. Strang, Brooks Cole, 2005

Course Objectives

▶ **How to think** *geometrically* **in** *vector-valued* **signal and data spaces**.

▶ **How to** *solve linear and nonlinear inverse problems* **using basic quadratic optimization techniques**.

- How to use abstract geometric thinking when solving linear and nonlinear inverse problems in signal and data spaces.

▶ **Become comfortable with** *the process of moving back-and-forth* **between** *abstract mathematical solution techniques* **and** *practical engineering problems*.

- At the end of the quarter students will be able to apply abstract mathematical concepts to practical engineering problems.

Assumed Course Background

▶ **It is assumed that students know the material from linear algebra _well_.** As well as basic <u>complex variables</u> and (some) <u>probability</u>.

▶ The goal of this course *is not* to teach *fundamental concepts* of linear algebra (which *<u>you are assumed to already know</u>* from Math 20F, or the equivalent).

▶ The goal <u>is</u> to ensure that students are comfortable with the underlying *geometric concepts* associated with linear mappings between inner-product vector spaces and linear inverse problems encountered in many different *application domains* in engineering and science.

▶ Because the *students are assumed to already know linear algebra*, the course reading and homework will <u>*not*</u> be assigned in the order of presentation given in the textbook.

Assumed Programming Skills

▶ It is assumed that students know **Matlab,** or an equivalent high-level scripting language (such as python), well.

▶ Proficiency in Matlab or the equivalent is needed to perform the mandatory computer assignments which comprise 20% of your total, overall grade.

Course Performance Evaluation

▶ 10% Homework. 20% Computer Projects.
30% Midterm Exam. 40% Final Exam.
This breakdown is firm and non-negotiable.

- Homework (10%) is graded "A for <u>*Actual*</u> Effort". You get full credit <u>merely</u> for turning it in <u>***and***</u> *if it is evident that you worked on **all** of the problems.* You get partial (or even zero) credit if you are missing problems or it is clear that no real good faith effort was expended in attempting to solve the homework problems. You get no credit if you don't turn in the homework. Note that *the individual problems are <u>**not**</u> corrected or graded.*

- Computer assignments (20%) are *rigorously graded* for correctness of content and results, and for quality of the reports.

- Midterm (30%) and Final (40%) are *rigorously graded* for correctness of derivations and results.

- The Final Exam is scheduled for **Thursday, December 14, 2017, 3-6pm**. *<u>This date and time is firm and non-negotiable</u>*.

Student Collaboration & Cheating

▶ Students are **encouraged to** _discuss_ homework problems among themselves.

  - _Individual_ write-ups must be turned in.
  - Not understanding homework solutions will hurt you on the midterm and final exams which together comprise 70% of the overall course grade.

▶ Computer project _reports and coding_ must be done individually. You are allowed to _discuss_ the projects.

  - _Individually written_ code and reports must be turned in.
  - Identical, or unreasonably similar, overlap of code between two students will be perceived as cheating.

▶ Exams are _closed notes and closed book_.

▶ _Aggressive_ administrative action will be taken against students caught cheating.

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Course Topics - I

▶ Overview of (constrained and unconstrained) linear least squares and nonlinear optimization.

- Brief discussion of real-world linear and non-linear inverse problems encountered in engineering drawn from circuit analysis, robotics, GPS, and signal processing.

▶ Signal spaces as abstract vector spaces and matrices as representing linear mappings between signal spaces.

▶ Under- and over-constrained linear systems of equations and linear inverse problems.

- Well-posed and ill-posed linear inverse problems.

▶ Constrained and unconstrained quadratic optimization of linear systems (the "linear least squares" problem).

Course Topics - II

- Solutions to the linear least squares problem.

  - Relationship to the four fundamental subspaces of linear algebra.

  - The projection theorem, adjoint operators, the normal equation, generalized inverses, & the Moore-Penrose pseudoinverse.

- The Singular Value Decomposition (SVD) .

  - SVD and the four fundamental subspaces of linear algebra.

  - Use of the SVD to solve linear inverse problems and to obtain the Moore-Penrose pseudoinverse.

- Quadratic forms and weighted least-squares

  - Use in modeling energy, power, and uncertainty quantities encountered in engineering applications.

  - The weighted least squares problem and its relationship to the problem of maximum likelihood (MLE) estimation in statistics.

Course Topics - III

- Nonlinear least squares theory.
  - Vector differentiation and Hessians.
  - Necessary & sufficient conditions for an optimum to exist.
- Linearization-based nonlinear optimization techniques.
  - Iterative optimization techniques, including steepest descent, Gauss's method, and Newton's method.
  - Constrained nonlinear optimization and the method of Lagrange multipliers (time permitting).

Computer Programming Assignments (Two projects)

► For each assignment students will turn in an **"Engineering Technical Report"**

- You should write these up assuming that you will show them to prospective employers during job interviews.

- Students have had positive responses in job interviews.

► **1) Linear least-squares project.**

- Speech compression via differential coding.

► **2) Nonlinear least-squares project**.

- GPS positioning.